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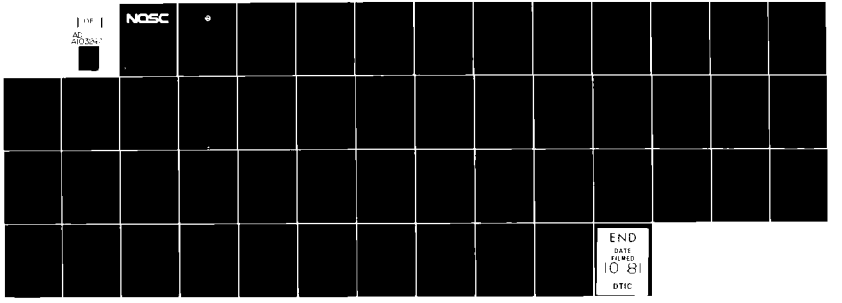

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Technical Document 442

THE IMPLEMENTATION OF TESTABILITY INTO MILITARY EQUIPMENT

Volume 1

D.D. Hall

30 April 1981

Final Report: July 1980—April 1981

Prepared for
Chief of Naval Material

Approved for public release; distribution unlimited

NAVAL OCEAN SYSTEMS CENTER
SAN DIEGO, CALIFORNIA 92152

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AN ACTIVITY OF THE NAVAL MATERIAL COMMAND

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Commander

HL BLOOD
Technical Director

ADMINISTRATIVE INFORMATION

This technical document describes a plan for the implementation of testability into military equipment via the military specification process. The plan was developed by personnel of the Information Transfer Division (NOSC Code 825) in support of the Naval Ocean Systems Center Test Technology Office. This technical document incorporates analysis performed by ManTech International Corporation, under contract N00123-79-C-0422 under O&MN funding from NAVMAT. The principal investigator for ManTech was Mr. T. C. Chapman. Mr. A. C. MacMurray was the Contracting Officer's Technical Representative.

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A plan for the development and modification of military standards, specifications, and handbooks for the purpose of making the design discipline of testability a reality in equipment procurements and designs has been developed. This plan is based on an analysis of existing related documents and a "systems approach" to the problem of management and control of this design area via the specification process. The overall problem was segmented into six functional areas for solution which is presented in the form of specific recommendations for each area. It is intended that the plan be used as the foundation for a program to develop the documents needed to make testability happen in military equipment. This plan could also serve as a model for similar efforts in other design areas.

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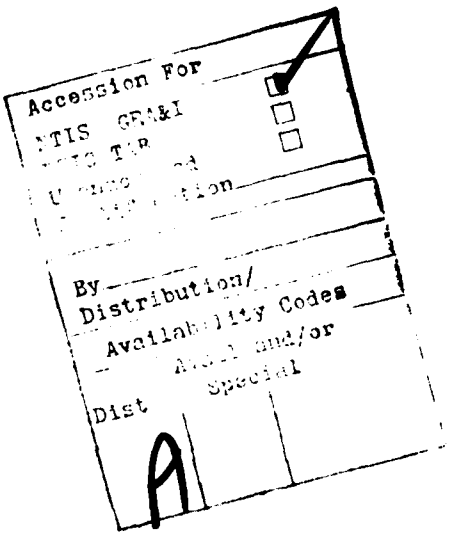
20. ABSTRACT (Continued)

This technical document is provided in two volumes. Volume 1 presents the description of the problem, work accomplished, and results. The results are presented as general recommendations for creation, modification, or deletion of specific military documents. Volume 2 contains supporting appendices that provide more detailed recommendations for modification of some existing documents as well as supporting analytic material.



SUMMARY

OBJECTIVE

This Technical Document presents a plan for the implementation of testability into military equipment. The plan advocates the generation and modification of official MIL-type documents in order (1) to establish testability as a design discipline and (2) to result in a family of testability documents that can be applied when procuring military hardware. This plan consists of specific recommendations in six functional areas comprising testability.

APPROACH

The task was accomplished in two parts. The first part entailed grouping existing and proposed military standards and design guidance notebooks that relate to testability under the following testability headings:

- Management
- Technical Requirements
- Design Guide
- Documentation
- Validation
- Interfaces

The second part was accomplished by analyzing these groups of documents, noting deficiencies and making recommendations to alleviate these deficiencies. In addition, a survey of other agencies and commercial companies was performed to determine if progress toward the objective was being made elsewhere.

RESULTS

Specific recommendations were made in each functional area. These recommendations as they apply to existing and proposed MIL-documents are summarized below:

Proposed New Documents:

Military Standards

MIL-STD-ABC	Testability Program Requirements
MIL-STD-DEF	Testability Demonstration

MIL-STD-GHI Testability Analysis and Report

MIL-STD-XXXX System Level Performance Monitoring

Design Guides

Design for Testability Guide

Performance Monitoring Design Guide

Modification - Proposed to Existing Documentation:

Military Specifications

MIL-E-16400

MIL-T-24309

MIL-T-28800

Other general equipment specifications based on MIL-STD-454

Military Standards

MIL-STD-415

MIL-STD-454

MIL-STD-490

MIL-STD-1521

MIL-STD-2076

MIL-STD-2077

MIL-STD-2111

Cancellation - Proposed

MIL-STD-1326

MIL-STD-1345

MIL-STD-1519

CONCLUSION

The plan presented herein provides the necessary framework for a program to develop these documents as well as for the definition of their content, organization and relationships. This framework is sufficient for the structuring of specific tasks in each functional area in order to achieve highly testable design in military equipment.

NOTE: Testability is a design characteristic which allows the status (operable, inoperable, or degraded) of a unit (system, subsystem, module or component) to be confidently determined in a timely fashion.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

FIGURES

1.0 INTRODUCTION

The requirement to treat testability as an independent valid design objective within the scope of manual and automatic testing, has been recognized only recently. In the past, testability was documented by inference within other areas such as maintainability and reliability. As a result, many varied testability-related documents currently are in print, in use, and being proposed. These documents have been developed over a period of many years and are generally specialized for the individual needs of the varied users. This results in a number of differing methods for achieving testability in hardware. In some cases these documents are also limited by the state of the technology at the time they were written. Additionally, varying degrees of conflict, overlap, and duplication exist between these documents. It is therefore expedient for the testing technology community to review the present state of testability-related documentation to determine the best approach for using existing documents and for creating new ones.

This report presents a "systems approach" to the review of testability-related documents. It also presents the information which discloses the level of conflict, overlap, and duplication between current testability-related documentation. This includes segmentation of the subject into major areas of interest. Areas that may require changes or the writing of new documents are identified and appropriate recommendations are given. The end result is a guide for the development of a family of testability documents that can be applied during the procurement phase of shipboard hardware, and will aid in the achievement of a high degree of testability and self-test features in the hardware.

2.0 BACKGROUND

The Testing Technology Office at the Naval Ocean Systems Center (NOSC, Code 921) is currently investigating the need for revisions to military standards and other documents that affect testing and performance monitoring. This need has been identified as arising from:

- Testability, as treated in existing documentation, is neither recognized as a design discipline in its own right, nor is it explicitly mandated;
- Program managers having cognizance over equipment development efforts, have no single cohesive thread of documentation from which to evoke this design discipline in their programs;
- Some existing documentation does not reflect the latest technology;
- Potential areas of conflict or incompatibility exist between existing standards and guidelines, as well as those being prepared in response to new requirements.

In the course of the investigation, it was apparent that the application of a "systems approach" to the organization of these standards would prove the most effective method of resolving these issues. The term "systems approach" simply means to scope out and define the entire problem prior to the definition of the solution and to maintain this viewpoint when delimiting each piece of the solution. This approach resulted in the present definition for subsequent generation of a family of testability-related documents for use by Testability Engineers as well as Program and

Acquisition Managers. This family of documents will allow the establishment of testability as a design discipline at the same level as the requirements for performance, reliability, maintainability, etc. The development of shipboard hardware during the R&D phase is a mix or compromise between the various engineering disciplines. In the past, the engineering discipline of maintainability has been the primary method of implementing testability into the hardware. The primary proof of testability has been the maintainability demonstration test which occurs during qualification testing. The main thrust of this test is aimed more at the mean-time-to-repair (MTTR) rather than the testability of the hardware. The MTTR figure can be met using a relatively untestable hardware design by relying on a sufficiently complex test scheme. Testability impacts the efficiency of testing as well as the MTTR.

Establishing testability as a design discipline will place it at an increased attention level when the cost and engineering trade-offs are performed during the R&D phase of the hardware development. This will increase the testability of military hardware because it is more cost effective and practical to design testability into the prime equipment than to develop elaborate test schemes to overcome design deficiencies.

3.0 APPROACH

A two phased approach was taken. In the first phase, a survey was conducted over a wide range of military standards, specifications and design guidance notebooks. A total of 23 existing and proposed documents were included on the basis of their potential impact on or association with testability. Each document was analyzed in the following categories:

- Major topics
- Level of detail
- Area of coverage
- Constraints
- Overlap between documents
- Contributions toward testability

Some of the documents surveyed specify requirements in the related fields of maintainability and reliability. They were included because they have potential impact on testability. However, they also can serve in an instructional capacity due to the fact that they support relatively mature but related design disciplines. Thus, the previous experience and example expressed in the maintainability and reliability documents could be used in this effort. Specifically, the relationship of the general equipment standards and specifications was examined with respect to reliability, maintainability and related fields.

The second phase was based on hardware procurement considerations. From the aspect of procurement, it was found that each document or group of documents support one or more functions as follows:

- An overall management document for conducting a testability program;
- A group of documents that addresses the testability technical requirements for hardware;
- A group of documents, such as a Design Guide, which aid the contractor in implementing testability into the hardware;
- A group of documents that specifies how the testability data is to be prepared and presented (Design Review Data, Technical Requirements Data [TRD], Test Programs Sets [TPS], etc.);
- A document that specifies the methods for the validation of testability (demonstration tests);
- A group of documents that specifies the interfaces, data transfer, electrical characteristics, and sensor selection in support of test/monitoring.

An analysis was conducted on a function by function basis. Final conclusions were then collected and summarized into recommendations.

Additionally, a survey of "other agencies" and commercial companies was performed to ascertain the procurement methods being used to obtain testability of hardware. This was to get an indication of the present state of testability relative to current procurement practices. The following agencies and commercial companies were surveyed:

- U.S. Air Force, Air Force Logistics Command, MATE Program;
- U.S. Army Communications Research and Development Command (CORADCOM); Direct Support Automatic Test Support System (DS-ATSS) Program;
- Boeing Company, Commercial Airplane Division;
- Lockheed, Commercial Airplane Division;
- NASA.

The methods currently being used by the groups surveyed at the time of this report are as follows:

U.S. Air Force, MATE Program

These Modular Automatic Test Equipment (MATE) Testability guides were not available for review because they are competition sensitive. The significant factor is that the subcontractors are presenting their methodology for testability to the Air Force, as opposed to the Air Force Logistics Command designating the methodology.

U.S. Army, CORADCOM

The group at the U.S. Army Communications Research and Development Command (CORADCOM) do not have testability standards. Instead, they have taken information from an independently funded testability design study and developed a testability portion of a hardware RFP for "Direct Support Automatic Test Support System (DS-ATSS)". At the time of this report, the submitted proposals had not been evaluated. Testability requirements were placed in the performance specification, and data items in accordance with the following DIDs, were requested. Appendix C contains these DIDs in their entirety.

Item	DID
Testability Program Plan	DI-A-XXX1
Testability Analysis Report	DI-R-XXX2
Test Requirements Document	DI-T-3734A
Testability Demonstration Plan	DI-T-XXX4

Except for the Test Requirements Document, the data items are new.

Boeing

To achieve testability in hardware, the Boeing Commercial Airplane Division utilizes maintainability requirements, implementation of these requirements by the hardware subcontractor, and design reviews and testing. They do not have testability-only documents, nor do they treat testability as a separate discipline. Testability related requirements are placed in the procurement specification.

Lockheed

The approach utilized by Lockheed is similar to that used by Boeing. The pertinent factor being they do not have a specific "Testability Document", but use maintainability requirements to achieve testability.

NASA, Space Shuttle, Orbiter

NASA has taken the position that most of the hardware for the Orbiter portion of the Space Shuttle will be repaired by the individual suppliers and testability would not be cost effective. They justify this since most of the hardware is low volume and off-the-shelf.

The "Other Agencies" surveys resulted in the following general conclusions:

- Testability requirements as a design discipline are not generally specified in current acquisition documents;

- Maintainability requirements continued to be the most common method of installing testability;

- The maintainability and testability requirements are placed in the "Requirements" section of specifications. The inclusion of these maintainability and/or testability requirements by the procuring activity without the aid of any associated "Testability Documents" is prevalent.

  NOTE: An exception to the use of maintainability as a method of achieving testability is being attempted by the U.S. Army CORADCOM, DS-ATSS program. However, the program has not progressed sufficiently to provide any concrete conclusions.

4.0 RESULTS

The results of this study are presented by testability function. These testability functions are as follows:

Testability Function	Paragraph
Management	4.1
Technical Requirements	4.2
Design Guide	4.3
Documentation	4.4
Validation	4.5
Interfaces	4.6

The Testability Matrix, Figure 1, depicts the testability document grouping by function along with deficiencies/recommendations by function.

4.1 MANAGEMENT

Testability has not been generally treated as a separate discipline and therefore, except for the proposed MIL-STD-XXX (W. Keiner) "Testability Acquisition Program Requirements for Electronic Equipments and Systems", there are no documents solely dedicated to the overall management and validation of testability. Testability as a design discipline is a management function. The function of testability management during the procurement phase of development requires a MIL-STD similar to MIL-STD-470 (maintainability) and MIL-STD-785 (for reliability). The document "A Study of Testability Standardization for Electronic Systems and Equipment" (W. Keiner), contains the testability management elements with which to develop a testability management document, MIL-STD-ABC (Proposed). "Testability Acquisition requirements for

TESTABILITY FUNCTION / DOCUMENT	MANAGEMENT	TECHNICAL REQUIREMENTS	DESIGN GUIDE	
MIL-STD-ABC (Proposed)	Testability Program			
MIL-STD-XXX (Proposed) W. Keiner MIL-E-16400 MIL-T-28800 MIL-STD-454 MIL-STD-415		Testability Reqmts. Equipment Spec. Equipment Spec. General STD. Testability Reqmts.		
Built-In Test (BIT) Design Guide Operational Monitoring (ORMS) Design Guide (Proposed) Design for Testability Guide, W. Keiner (Proposed) MIL-STD-1390 MIL-STD-1364			Released Design Guide (Proposed) (Proposed) Level of Repair GPETE	
MIL-STD-1519 MIL-STD-1345 MIL-STD-2076 MIL-STD-2077 D-790 MIL-T-24309 MIL-STD-2111 MIL-STD-24255 MIL-STD-490 MIL-STD-GHI (Proposed) MIL-T-24424 MIL-STD-3110 MIL-STD-1521				TR TR TR TP TP TS TR TR Sp Te TR RO DS
MIL-STD-471 MIL-STD-DEF Demonstration (Proposed) Testability				
MIL-STD-XXXX (Proposed) NOSC) MIL-STD-1657 SDMS (I/O Modules) MIL-STD-1553 MIL-STD-1397 DOD-STD-1399 IEEE-STD-488 MIL-STD-X, On-Line/Off-Line Interface (Proposed) MIL-STD-1326				
Deficiencies	A document does not exist in released form to manage a testability program by an R&D contractor.	Testability as a discipline does not exist in equipment specs or general standards.	Need an operational monitoring and design for testability guide to bridge educational gap.	Te me tio tes TR uni
Recommendations	Utilize W. Keiner study to develop a testability program document along with supporting DID's.	Change the equipment specifications and MIL-STD's to include testability as a design discipline.	Draft an operational monitoring design guide. Convert the W. Keiner testability course to a testability design guide.	Co Ke an a u do ST ba

Figure 1. Testability Matrix

TS	DESIGN GUIDE	DOCUMENTATION	VALIDATION	INTERFACES
	Released Design Guide (Proposed) (Proposed) Level of Repair GPETE			
		TRD TRD TRD TPS TPS TSP TRS TRS Specification Practices Test. Anal. & Report TRS ROR DSN Reviews/Audits		
			Maintainability Test Testability Demonstration (Proposed)	
				System Level Monitoring (Proposed) Physical Interface Equipment Spec. Series Data Bus Computer Interfaces Shipboard Interface Parallel Data Bus (Proposed) On-Line Testability
line ipment dards.	Need an operational monitoring and design for testability guide to bridge educational gap.	Testability analysis document not released. Duplication in TRD area. Testability test document not released. TRD and TPS documents not universal.	MIL-STD-471 does not place priority on how well the test equipment works, but how long it operates.	Interfaces for shipboard hardware, both on-line and off-line have not been standardized.
t -STD's s a	Draft an operational monitoring design guide. Convert the W. Keiner testability course to a testability design guide.	Convert a portion of W. Keiner study to a testability analysis document. Develop a universal TRD and TPS document utilizing MIL-STD's 2076 and 2077 as a base.	Convert a portion of the W. Keiner study to a testability MIL-STD for validation.	Standardize the interface for both on-line and off-line shipboard hardware.

Figure 1. Testability Matrix

2

Electronic Equipment and Systems" (MIL STD-XXX, Proposed) will also assist greatly in testability management. The proposed allocation of technical data from these reports is presented in the Technical Requirements section of this report. The establishment of testability as a design discipline and the organizational role of the testability engineer are examined in the material to follow.

4.1.1 TESTABILITY ENGINEERING

The discipline of testability emerged primarily through the maintainability function. Therefore, consideration must be given to maintainability and similar disciplines to review the pitfalls that accompanied their emergence as entities. Similar difficulties for testability can then be avoided.

Historically, in engineering companies, maintainability has been a support function, not part of the performance design engineering team. As such, it has been staffed under an engineering support or quality assurance group along with reliability. This tends to give the discipline a classical watchdog (quality assurance role) connotation which tends to form a barrier between the performance design engineering team and the maintainability/reliability engineers. The maintainability/reliability functions achieve the most efficient implementation when a working group relationship is established with the performance design engineering group.

To date, the implementation of testability into the hardware has not been a high priority item even within the scope of a maintainability demonstration. During such demonstrations, the contractor usually supplies (and thus controls) the list of faults along with their implementation, and thus assures the successful passing of the test despite the presence of any testability shortcomings. Classically the implementation of testability has been handled by assigning the design effort to the same engineer that had the design responsibility for performance. This usually causes a priority and time scheduling problem that results in testability being relegated to a "when time permits" situation. Also contributing to the problem is the fact that the performance design engineer does not normally have the experience or background in testability-related disciplines (ATE, ATLAS, TPS, etc.) which are instrumental in achieving a testable design.

In any consideration of adding the testability function to the duties of maintenance or reliability engineers. the following considerations must be made:

- Maintainability engineers tend to be involved in the "packaging" of the hardware by function, performing maintainability predictions, and in the maintainability demonstration tests, along with monitoring the design;
- The reliability engineer is involved with parts procurement, parts application, reliability prediction, failures, and the reliability demonstration tests, along with monitoring the design;
- Because of the function of testability, (i.e., the confident timely determination of equipment status), the testability engineer must be more hardware design oriented than the maintainability and reliability engineer.

Due to the differences in the design disciplines of testability as compared with maintainability and reliability, the testability function is optimized by assigning the testability engineer as part of the performance design engineering team. The enhancement of the working relationship between the testability engineer and performance design engineers should increase the application of testability into the design process.

4.1.2 TESTABILITY ENGINEERING EFFECTIVENESS

Effective development of hardware during the design phase is a composite of all engineering disciplines which results in a cost-effective design. All design disciplines (including testability) have to be designed in, not tested in after the fact. The establishment of testability as a design discipline through testability requirements, Contract Data Requirements List (CDRL) items, and a testability demonstration test will result in more testable hardware.

The effectiveness of the testability engineering role will depend on the following:

- A close working relationship with the performance design engineering team;
- A testability demonstration test as part of the qualification tests. This places importance on testability as a design discipline, an attention getter. Testability test results should also be considered as Design Review, Audit (FCA/PCA) requirements;
- A clearly defined testability requirement in the performance specification. This avoids ambiguities when design trade-offs are performed which affect performance, testability, maintainability, reliability, safety, etc.;
- Status as a design discipline equal to performance, maintainability, reliability, safety, etc. This is achieved by program requirements which are attention getters for the testability discipline. These program requirements are as follows:
  - Testability Program Plan;
  - Testability Analysis;
  - A subject for the Preliminary Design Review (PDR) and Critical Design Review (CDR) as specified in the performance specification, proposed testability requirements, MIL-STDs and CDRLs;
  - Testability demonstration test as part of the qualification tests.

4.2 TECHNICAL REQUIREMENTS

Technical requirements pertain to those testability conditions that are specified to a contractor for the purpose of delineating desired limits on the hardware design. These testability requirements are in MIL-equipment specifications, MIL-STDs and the hardware performance specification.

The hardware performance specification (per MIL-STD-490) is the starting place for the analysis herein, followed by the MIL-equipment specifications and testability MIL-STDs.

The following documents, as shown in Figure 1, are grouped under the Technical requirements function:

- MIL-STD-XXX Proposed, W. Keiner, Testability Acquisition Program Requirements for Electronic Equipments and Systems;
- MIL-E-16400, Electronic Equipment, Naval Ship and Shore: General Specification;
- MIL-T-28800, Test Equipment for use with Electrical and Electronic Equipment, General Specifications for;
- MIL-STD-454, Standard General Requirements for Electronic Equipment;
- MIL-STD-415, Test Provisions for Electronic Systems and Associated Equipment, Design Criteria for.

4.2.1 HARDWARE PERFORMANCE SPECIFICATIONS

These hardware performance specifications are drafted to the applicable appendix of MIL-STD-490, "Specification Practices". This standard does not currently make provisions for testability as a specification item, as it does for maintainability and reliability. MIL-STD-490 is discussed here only in the context that testability requirements are placed in the hardware performance specification. MIL-STD-490 is grouped in the Testability Matrix, Figure 1, under the documentation function.

4.2.2 APPLICATION OF REQUIREMENTS

The application of a given program design discipline to a family of military equipment specifications is dependent upon the ability to pass requirements associated with that particular discipline from general documents to detailed equipment specifications. The requirement of maintainability, as applicable to electronic equipment design, is used in the following example since it is a long acknowledged design discipline.

4.2.2.1 Maintainability Example

General specifications, such as MIL-E-16400 for electronic equipment and MIL-T-28800 for test equipment, specify requirements for maintainability (as well as other acknowledged program disciplines). These requirements are consolidated and standardized in MIL-STD-454, "Standard General Requirements for Electronic Equipment". Certain of these requirements complement each other in application to equipment design and can be categorized as hardware and program (design discipline) requirements as follows.

Design Discipline Requirement	Hardware Requirement
Req. 54 - Maintainability	Req. 7 - Interchangeability
	Req. 36 - Accessibility

It can be seen that the subjects of "interchangeability" and "accessibility" are maintainability hardware requirements.

Having determined the applicable requirements (still using Maintainability as an example), the functions of each along with applicable documents, are specified in the general standard (MIL-STD-454) as follows:

- **Maintainability**

Maintainability Program	MIL-STD-470
Maintainability Prediction	MIL-HDBK-472
Maintainability Verification	MIL-STD-471

- **Accessibility**

Definition of Item Levels, Item Exchangeability Models, Related Terms, etc.	MIL-STD-280

This hierarchy of documents for maintainability is depicted in Figure 2.

4.2.2.2 Proposed Application for Testability

The application of testability to a family of specifications necessitates that applicable requirements be passed or traced from specific testability-oriented documents to general ones. As with maintainability, the starting point for examining this flow is the equipment level specifications (MIL-E-16400, MIL-T-28800, etc.), followed by a general requirements document (MIL-STD-454) that specifies hardware and program (design discipline) requirements and documents. A problem becomes apparent in the application of testability as a design discipline, due to the appearance of voids in testability requirements and documentation. For example, the equipment specifications (MIL-E-16400 and MIL-T-28800), and the general standard (MIL-STD-454) do not presently contain testability program (design discipline) requirements. Therefore, modification of MIL-E-16400 and MIL-T-28800 (*et al)* is necessary to draw these requirements from testability documents. Similarly MIL-STD-454 will need modification to include testability as a program requirement which will specify a family of testability program functions and documents as follows:

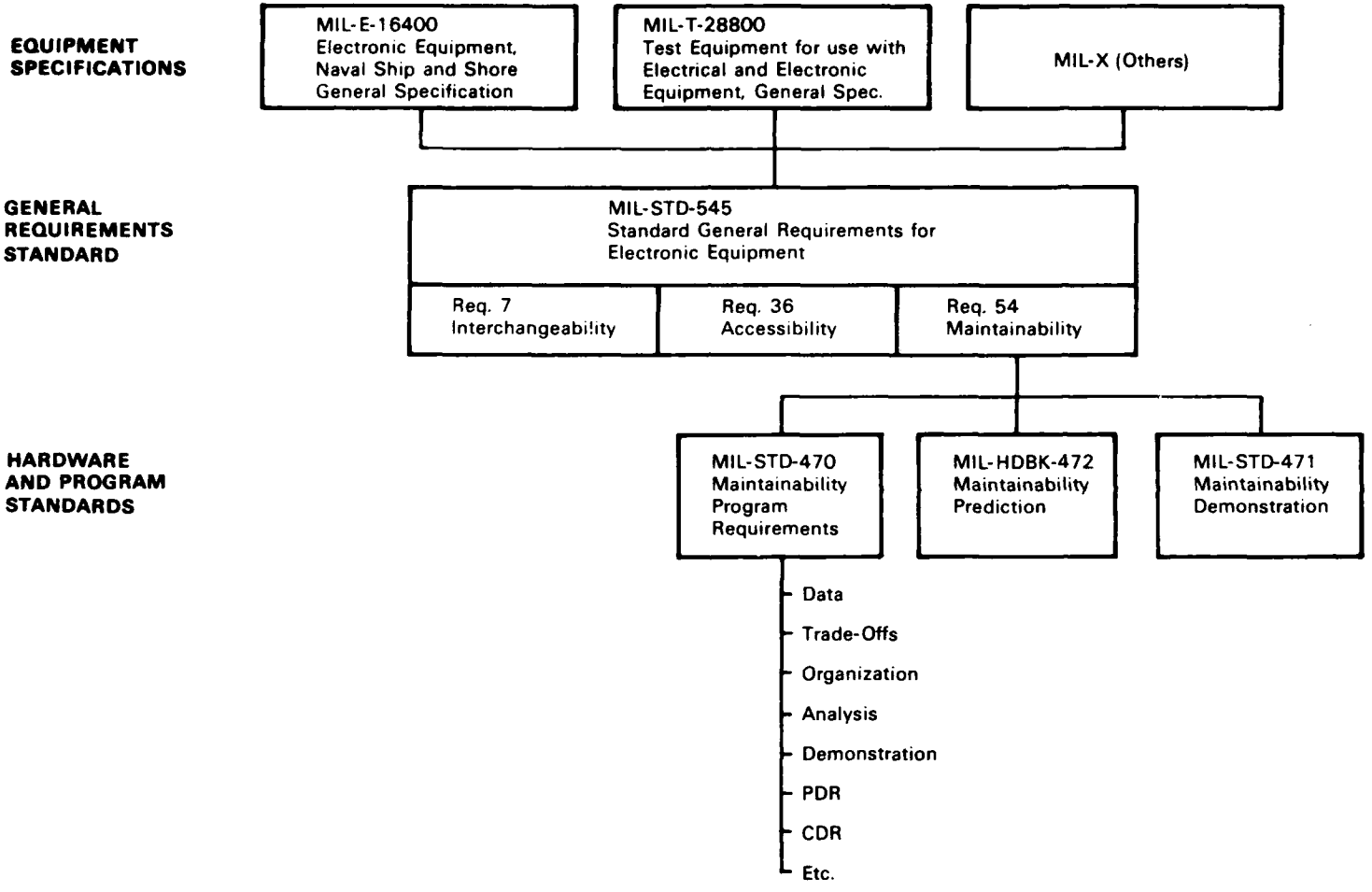


Figure 2. Maintainability Hierarchy of Documents

MIL-STD-454

Design Discipline Requirement	Hardware Requirement
Requirement XX Testability (Proposed)	Req. 32 -Test Provisions
	Req. YY - Interfaces (Proposed)

It should be noted that Requirement 32 "Test Provisions" contained in MIL-STD-454 is a testability hardware requirement. This requirement needs to be updated to include interface requirements and/or add a new MIL-STD-454 Requirement YY, Interfaces. This allows for testability hardware and program requirements in MIL-STD-454 that may be applied in parallel as with maintainability requirements. The W. Keiner study, "A Study of Testability Standardization for Electronic Systems and Equipment", contains the testability counterparts to maintainability. The data contained in the proposed W. Keiner document could be used to develop a family of testability documents by function similar to the family of maintainability documents. This family of MIL-STD-454 specified testability program documents is proposed as follows:

- **Testability**

Testability Program Requirements	MIL-STD-ABC (Proposed)
Testability Demonstration	MIL-STD-DEF (Proposed)
Testability Analysis and Report	MIL-STD-GHI (Proposed)

- **Test Provisions**

Test Provisions for Electronic Systems and Associated Equipment, Design Criteria for	MIL-STD-415

- **Interfaces**

TBD	TBD

The proposed hierarchy of testability documents is illustrated in Figure 3.

4.3 DESIGN GUIDE FUNCTION

The establishment of testability as a design discipline will require more than specifying requirements in MIL-STDs, Statements of Work (SOWs) and performance specifications. The design engineers that are involved in the performance aspects of the hardware do not normally have background or experience in testability. The design engineers that have testability experience are usually involved in designing test equipment, not operational hardware.

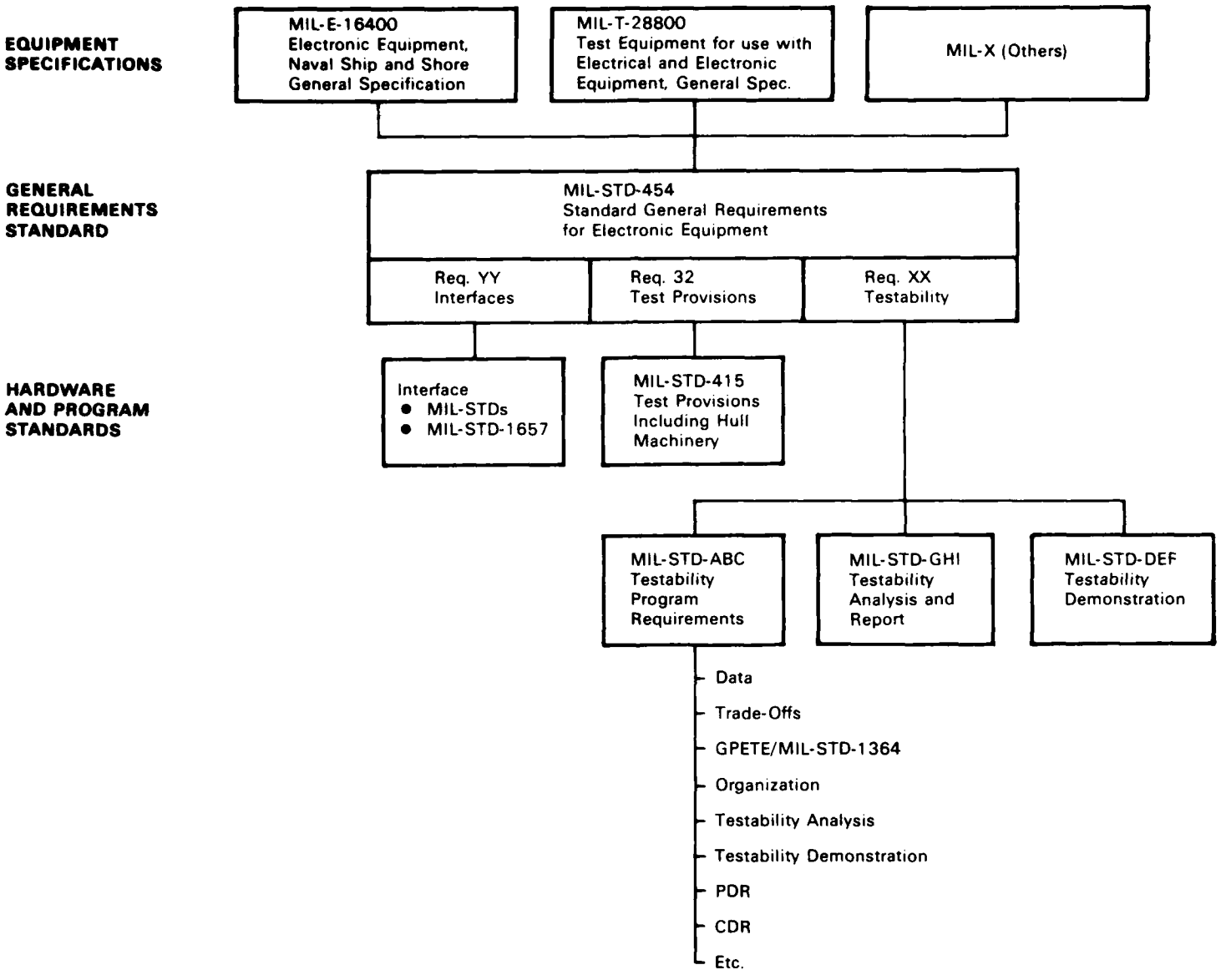


Figure 3. Testability Hierarchy of Documents (Proposed)

An educational process will naturally occur when testability is implemented as a design discipline. This educational process will either occur through trial and error or through the use of planned documentation. The use of testability design guides will help bridge this potential educational gap.

4.3.1 BUILT-IN-TEST DESIGN GUIDE (BIT)

The Built-In-Test (BIT) Design Guide is currently available for use in hardware procurement and may be updated and expanded as new techniques and electronic components become available. Although the BIT Design Guide discusses operational monitoring, it is primarily associated with Go/No-Go testing. The classical Go/No-Go testing concept is normally based on reporting that the hardware is either operational or non-operational.

Early BIT efforts were developed to meet the maintenance concept; that is, how to determine if the equipment is ready to operate and how to isolate a failure. How well it was working was not a driving consideration.

4.3.2 OPERATIONAL MONITORING (ORMS) DESIGN GUIDE (PROPOSED)

Operational monitoring (part of ORMS concept) is involved with how well the equipment is operating. This is required to assess the degree of performance and/or degraded performance capability of shipboard hardware. The current BIT Design Guide does not stress methods of implementing operational monitoring. The addition of special "Operational Monitoring" sections or the development of a separate "Operational Monitoring Design Guide" will help in the testability educational process.

4.3.3 DESIGN FOR TESTABILITY GUIDE

The conversion of the W. Keiner "Design for Testability Course" to a written design guide would be a beneficial primary document for the testability educational process. The BIT and the proposed ORMS design guides would be related specialized documents.

4.3.4 MIL-STD-1390, LEVEL OF REPAIR

MIL-STD-1390, Level of Repair (LOR), is placed in the same category as the design guides because of its value in performing testability design trade-off studies by the hardware development contractors. Normally the LOR is used during the acquisition phase in determining the maintenance concept. During the design of the hardware, after the maintenance concept has been established, the LOR may be used to perform those hardware design/cost trade-off studies that affect testability.

4.3.5 MIL-STD-1364, STANDARD GENERAL PURPOSE ELECTRONIC TEST EQUIPMENT

This MIL-STD for general purpose electronic test equipment (GPETE) was placed under the design guide function because the selection of GPETE can be recommended, but not dictated by contract. The GPETE listed in MIL-STD-1364 would be a "first-advice" shopping list for use by the hardware development contractor. This document and the preceding cited and proposed guide-type documents would be discussed in the statement of work and supplied as part of the Request for Proposal (RFP) package. They would not be invoked contractually, but would be supplied as "information only" documents to be used by the contractor as he sees fit.

4.4 DOCUMENTATION

The following documents, as shown in Figure 1, are grouped under the Documentation function:

- MIL-STD-1519, Test Requirements Document, preparation of;
- MIL-STD-1345, Data, Measurement, in Support of Maintenance, Calibration, and Repair of Electronic Equipment;
- MIL-STD-2076, UUT Compatibility with ATE, General Requirements for;
- MIL-STD-2077, Test Program Sets, General Requirements for;
- D-790, Test Program Sets, General Requirements for, NESEC SD STD;
- MIL-T-24309, Technical Support Plan for Electronic Equipment;
- MIL-STD-2111, Technical Repair Standards (4G Repairables), Preparation of (Draft);
- MIL-T-24255, Technical Repair Standards, Submarines;
- MIL-STD-490, Specification Practices;
- MIL-STD-GHI (Proposed), Testability Analysis and Report, Preparation of;
- MIL-T-24424, Technical/Maintenance Overhaul and Repair Standards;
- MIL-STD-3110, Restoration, Overhaul, and Repair of Electronic Equipment;
- MIL-STD-1521, Technical Reviews and Audits for Systems, Equipments, and Computer Programs.

4.4.1 DOCUMENTATION FUNCTION

The testability documentation function relates to those documents that require the drafting or submittal of testability related data. This data may be required at Preliminary Design Reviews (PDR), Critical Design Reviews (CDR), and audits; in addition to being cited by Contract Data

Requirements List (CDRL) item required by contract. The types of testability data are as follows:

- Performance Specification (MIL-STD-490);
- Testability Analysis and Report (Proposed MIL-STD-GHI);
- Test Requirements Data (TRD);
- Testability Demonstration (Proposed MIL-STD-DEF);
- Technical Support Plan (TSP);
- Test Program Sets (TPS);
- Technical Repair Standards (TRS);
- Restoration, Overhaul, and Repair (ROR);
- Technical Reviews and Audits.

The flow of testability related data will generally follow the top-to-bottom sequence depicted in Figure 4, Testability Documentation Tree. A discussion of these testability data items is presented in the following sections. A more detailed analysis of selected documents pertaining to documentation is contained in Appendix A, Document Survey.

4.4.1.1 Performance Specification

The performance specifications are formatted per MIL-STD-490. MIL-STD-490 is placed under the documentation section (para. 4.4) for this report because these specifications, depending on production volume, eventually become hardware equipment specifications. MIL-STD-490 was also referenced under the Technical Requirements section (para. 4.2) because the original RFP performance specifications contain testability design requirements. MIL-STD-490 does not currently contain specific testability sections as it does for reliability and maintainability. This is required to establish testability as a design discipline. See Section 4.2, Hardware Performance Specifications.

4.4.1.2 Testability Analysis and Report

The Testability Analysis and Report (MIL-STD-GHI, Proposed) is a proposed fall-out from the W. Keiner report, "A Study of Testability Standardization for Electronic Systems and Equipment". This analysis will provide qualitative and quantitative data that determine the equipment's ability (or lack of ability) to pass a testability demonstration test. This MIL-STD will contain provisions for a Testability Analysis Report (TAR) for documenting results of the testability analysis. The TAR will be presented at PDR/CDR audits, and will be delivered per CDRL item instructions. This testability analysis is in addition to the maintainability analysis. The prime concern will be the determination that the quantitative changes (deltas) are detectable at the interfaces following a failure. This may be implemented as a modified Failure Modes and Effect Analysis (FMEA) currently in use by reliability engineers. The modified portion of the

FMEA would be the quantitative changes at the interface in addition to the effect of the failure. These quantitative changes (deltas) would then be used to determine the tolerances and accuracy requirements of associated sensing equipment. This is the lead-in to Test Requirements Data (TRD) and the Testability Demonstration Plan (proposed).

4.4.1.3 Test Requirements Data (TRD)

The TRD will utilize data from the TAR. The TRD is currently covered in the following MIL documents:

- MIL-STD-1519, Test Requirements Document, Preparation of;
- MIL-STD-1345, Data, Measurement, in Support of Maintenance, Calibration, and Repair of Electronic Equipment;
- MIL-STD-2076, Unit Under Test Compatibility with ATE, General Requirements for.

A discussion of these MIL-STDs follows:

MIL-STD-1519

MIL-STD-1519 performs the same general function as Appendices A, C and D of MIL-STD-2076. MIL-STD-1519 is not set up to use ATLAS, whereas MIL-STD-2076 does.

MIL-STD-1345

MIL-STD-1345 works with MIL-STD-2111, "Technical Repair Standards (4G Repairables), Preparation of". MIL-STD-1345 is primarily a data document for the preparation and submission of data. This document is primarily associated with GPETE, not ATE.

Requirements for test procedures are specified as (a) performance test procedures, (b) fault location procedures, and (c) alignment procedures.

a. Performance test procedures are typified by those procedures developed by an equipment contractor for qualification and acceptance testing of the operational hardware. Normally this testing is not performed by ATE.

b. Fault location procedures are typified by those procedures used in, or in conjunction with, a Technical Repair Manual. Reference is not made relative to ATE which requires TPS (Example: MIL-STD-2077).

c. Alignment procedures are typified by those procedures used in a depot operation (Technical Repair Manual/Calibration Procedure).

In general, MIL-STD-1345 is not specifically set up for ATE. Data is specified, but not specifically for the generation of TPS.

MIL-STD-2076

MIL-STD-2076 was set up to work with MIL-STD-2077, Test Program Sets, and AR-10, (MIL-STD-2084, Proposed), "Maintainability of Avionics Equipment and Systems, General Requirements for". This MIL-STD used the terms "Avionics" and "WRA" which are not suitable for shipboard application. These avionic terms would need to be standardized to more general terms to make MIL-STD-2076 a more universal document.

Section 5.1.1, Design for Test on ATE. The contents of this section are not requirements, but rather recommendations and examples, and are more applicable in the "Testability Design Guide" (Proposed).

Section 5.1.2, Test Points, apply to, and should be inserted in MIL-STD-415, "Test Provisions for Electronic Systems and Associated Equipment, Design Criteria for".

Section 6.1.2, UUT Documentation Analysis and Hardware Inspection, are more functional in the following proposed documents:

- MIL-STD-GHI, Testability Analysis and Report
- MIL-STD-DEF, Testability Demonstration

NOTE: See Management and Technical Requirements sections of this study.

Appendix A, Test Requirements Data, with companion Appendices C and D, perform the same general function as MIL-STD-1519, "Test Requirements Documentation, Preparation of".

Appendix B, Compatibility Task Scoring Data: A scoring or rating system is more functional in the proposed MIL-STD-GHI, "Testability Analysis and Report". This type of analysis, if performed early in the R&D cycle (prior to PDR), can influence the design. If performed at or after the qualification testing, its function becomes passive.

Appendices C and D are as described in Appendix A.

Appendix E, "Application of UUT Failure Rate Data": This type of data can influence the design of the hardware and should be available prior to the PDR. This type of data is also more functional in the proposed MIL-STD-GHI, "Testability Analysis and Report".

Appendix F, "Fault Isolation (FI) Test Requirement, Fault Isolation Data": This appendix performs the same general function as MIL-STD-1345. The major differences are the use of functional and data flow charts (ATLAS Test Procedures) in MIL-STD-2076, while MIL-STD-1345 calls out detailed test procedures.

The TRD will be the data base for the following documents:

- Testability Demonstration Procedure
- Technical Support Plan (TSP)

- Test Program Sets (TPS)

4.4.1.4 Testability Demonstration (MIL-STD-DEF) Proposed

The content for Testability Demonstration Plan/Procedure/Report documents are contained in the W. Keiner report "A Study of Testability Standardization for Electronic Systems and Equipment". The testability demonstration plan, procedure and report documents will be CDRL items that will document the testability demonstration test.

Testability Demonstration Plan

The Testability Demonstration Plan delineates the test requirements and the general implementation of the testability testing. This allows for a meeting of the minds, between the procuring agency and the contractor, concerning the interpretation of the test requirements and their implementation. The Testability Demonstration Plan is expected to be drafted after the TAR and prior to the TRD (see Figure 4). The plan will be submitted for approval prior to the testability demonstration procedure.

Testability Demonstration Procedure

The Testability Demonstration Procedure will follow the TRD (see Figure 4). The procedure will specify the method of verifying the test requirements data.

Testability Demonstration Report

The Testability Demonstration Report follows the Testability Demonstration Test.

4.4.1.5 Technical Support Plan (TSP)

The TSP, MIL-T-24309, is an accumulation of all data that are pertinent to the support of equipment. Included in addition to testability data are:

- Maintenance concept;
- Plan for maintenance;
- Reliability design data;
- Maintainability design data.

The testability related data are specified as (1) modular construction and assembly design data, and (2) test point and test equipment data. The types of data specified in MIL-T-24309 are normally available as CDRL items separately, but not in one place. In the event MIL-T-24309 is to be specified, the following recommendation is submitted in the testability area:

- Modify paragraph 3.2.1.5, "Modular Construction and Assembly Design Data" and 3.2.1.6, "Test and Test Facilities Data", to reference information contained in the Test

Requirements Data (TRD) as specified in MIL-STD-1519, MIL-STD-1345, or MIL-STD-2076.

4.4.1.6 Test Program Sets (TPS)

The TPS documents available to the reviewer were MIL-STD-2077 and D-790. MIL-STD-2077 is a NAVAIR release while D-790 is an internal document prepared by NESEC. Generally speaking, the D-790 standard closely parallels MIL-STD-2077. Major differences are:

- D-790 terminology is more universal. For example, it does not use restrictive terms such as "avionics" and "NAVAIR". It tends to avoid use of MIL-documents in specifying requirements and is, therefore, ambiguous;

- MIL-STD-2077 is more definitive than D-790. It makes provisions for validation of the TPS by the Government agency, whereas D-790 is weak in this area.

Neither document is directly applicable to shipboard equipment. MIL-STD-2077 would have to be made less restrictive by broadening terminology beyond the scope of typical NAVAIR terminology, and D-790 would have to be more definitive in the area of requirements to be considered for status as a released MIL-STD.

NOTES: 1. MIL-STD-2077 is a companion document to MIL-STD-2076 as indicated by paragraph 5.10.1.1, "Program Design Data (PDD)" of MIL-STD-2077.

2. It is important to assure the software (TPS) is available in time to perform the testability demonstration. This potential time phasing problem will be made an item to be included in the testability demonstration plan. An ideal situation is to have the hardware design contractor develop the TPS to match the Government agency's test requirements.

Detailed comparisons of MIL-STD-2077 and D-790 are contained in Appendix A, Document Review.

4.4.1.7 Technical Repair Standards (TRS)

The TRSs are covered by the following documents:

- MIL-STD-2111, Technical Repair Standards (4G Repairables), Preparation of;

- MIL-T-24255, Technical Repair Standards (For Submarines Only);

- MIL-T-24424, Technical/Maintenance Overhaul and Repair Standards.

The discussion of these documents follows.

MIL-STD-2111

MIL-STD-2111 covers repair at the depot level of maintenance. This document was set up to work with MIL-STD-1345 and MIL-STD-1364. MIL-STD-2111 does not make specific

provisions for ATE and the supporting TPSs. MIL-STD-1345 is a TRD document, but not for ATE. The addition of an ATE section which references MIL-STD-2076 (TRD) and MIL-STD-2077 (TPS) would augment MIL-STD-2111. A more efficient approach would be to cancel MIL-STD-1345 and use MIL-STD-2076 for the TRD data, for the use of ATE and GPETE. This is based on the following:

- Appendix E of MIL-STD-2076 covers the non-ATE testing in terms of ATLAS in lieu of detailed test procedures;
- The detailed test procedures of MIL-STD-1345 call for specific test equipment which has the following limitations:
  - -- Identification of test equipment by model number (vendor) is limited and shows preference by manufacture.
  - -- A problem of substitution results in when the specific test equipment is not available at the depot in question.
  - -- The supporting TRD (ATLAS) will not be available in event ATE is to be used later.

MIL-T-24255

MIL-T-24255 was drafted for the overhaul of submarines, and does not apply directly to repair of hardware at a depot facility.

MIL-T-24424

MIL-T-24424 was drafted for the overhaul of ships. This document is similar to MIL-T-24255.

4.4.1.8 Restoration, Overhaul, and Repair (ROR)

MIL-STD-3110, Restoration, Overhaul, and Repair of Electronic Equipment, is listed under documentation because testing is a part of it. In the tier of documents, MIL-STD-3110 uses TRSs which are covered in MIL-STD-2111, MIL-T-24255, and MIL-T-24424.

4.4.1.9 General Purpose Electronic Test Equipment (GPETE)

The general purpose electronic test equipment (GPETE) is shown in Figure 4, Testability Documentation Tree, for those cases where ATE is not used. The GPETE data is specified in the TRD and used in the TRS and ROR documents. The TRS/ROR documents utilize the TRD, GPETE and TPS data.

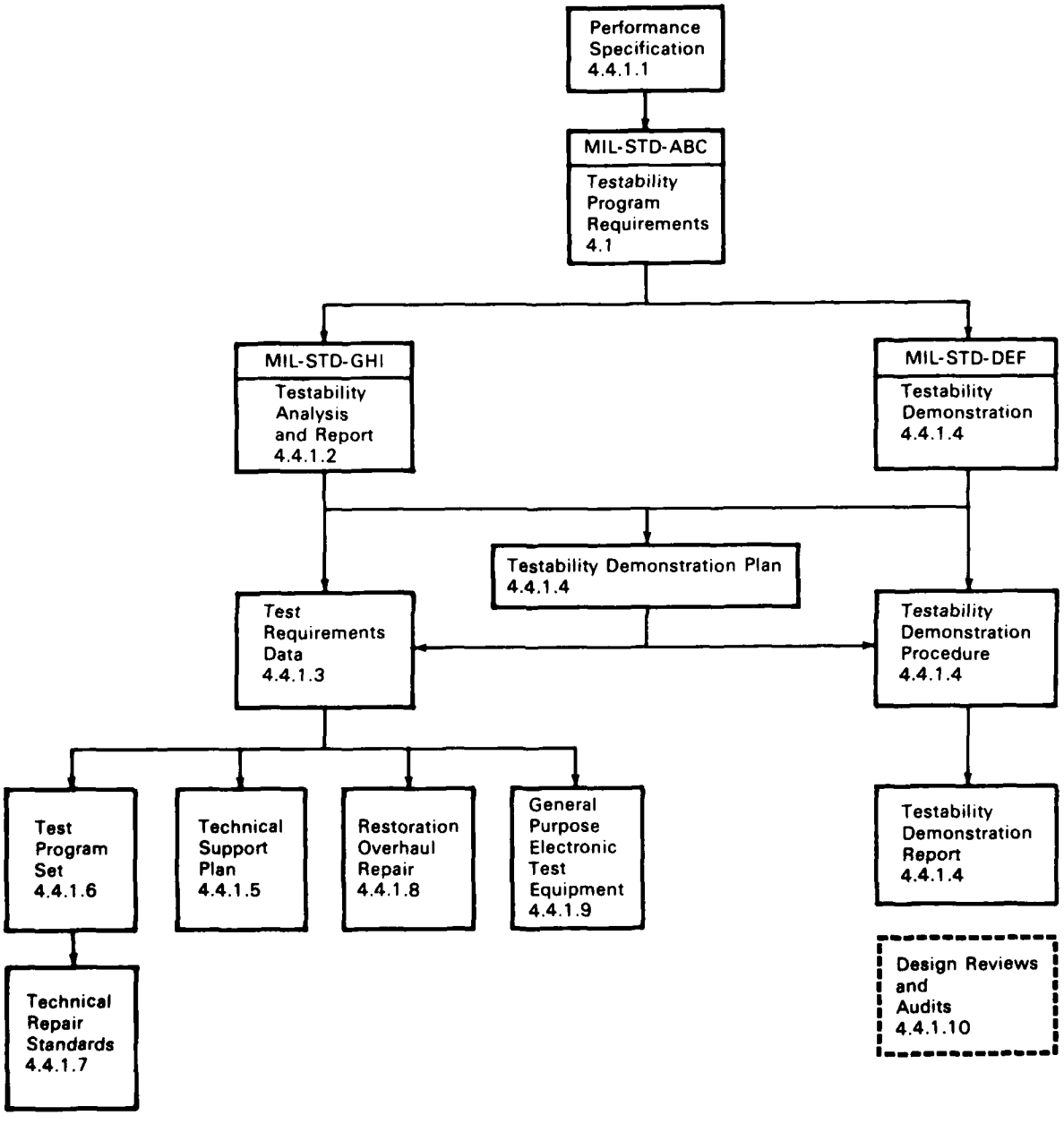


Figure 4. Testability Documentation Tree

4.4.1.10 Design Reviews and Audits

MIL-STD-1521 checklists contain maintainability, reliability and other data to be covered during design reviews and audits. No such provisions exist for testability.

4.5 VALIDATION

The following documents are grouped under validation, as shown in the Testability Matrix, Figure 1:

- MIL-STD-471, Maintainability Verification/Demonstration/Evaluation
- MIL-STD-DEF (Proposed), Testability Demonstration

Testability validation is performed as part of hardware qualification and acceptance testing. This also includes testability software. The purpose of these tests is to prove that the hardware design meets the testability requirements. Classically, the testability validation has been approached through the maintainability demonstration test per MIL-STD-471. The maintainability demonstration ruling parameter is the mean-time-to-repair (MTTR). The MTTR parameter can be reduced to the following time steps:

Function	Using
Detect	Test equipment or BIT
Isolate	Test equipment or BIT
Remove/Replace	Technician
Verify (retest)	Test equipment or BIT

The faster the test equipment or BIT operates, the more time is allowed to remove/replace. The total MTTR time is the sum of the individual function times. MIL-STD-471 restricts the time in which the test equipment must perform. This is to the direct detriment of the important testability factor of how well it performs.

Also, the selection of maintenance tasks for the maintainability demonstration is based on a stratification procedure; the intent being to "(a) allow for the selection of maintenance tasks in such a manner that the selection simulates the failure frequency of the test unit in actual operation (units with low MTBFs will be selected more frequently than units with higher MTBFs), and (b) ensure that a proportionately representative sample of task types/times are selected." A typical test is based on 50 tasks which are selected from 200 tasks. The 200 tasks along with the method of implementation are normally selected and submitted by the contractor. The customer will select 50 tasks from the 200. Since the contractor selects the 200 tasks, there is little chance that his hardware will fail the maintainability demonstration. With the contractor controlling the outcome of the maintainability demonstration and the controlling factor being the MTTR parameter, a question exists as to how testable the hardware design really is. The information contained in the

W. Keiner study, when formatted into a testability demonstration MIL-STD, would overcome the shortcomings of MIL-STD-471. This is not a recommendation to scrap MIL-STD-471, but to augment the maintainability demonstration with a testability demonstration either concurrently or at a different time.

4.6 INTERFACES

The following documents are grouped under the interface function in the Testability Matrix, Figure 1:

- MIL-STD-XXXX (NOSC Proposed), System Level Performance Monitoring, General Requirements for;
- MIL-STD-1657, Switch Equipment, Combat System, Command and Control, and Fire Control, Requirements for;
- Ships Data Multiplexer System (SDMS) (I/O Modules), Equipment Specification;
- MIL-STD-1553, Aircraft Internal Command/Response Time Division Multiplex Data Bus;
- MIL-STD-1397, Input/Output Interfaces, Standard Digital Data, Navy Systems;
- DOD-STD-1399, Interface Standard for Shipboard Systems;
- IEEE STD 488, 1978 Standard Digital Interface for Programmable Instrumentation;
- On-Line/Off-Line Interface (Proposed);
- MIL-STD-1326, Test Points, Test Point Selection and Interface Requirements for Equipment Monitored by Shipboard On-Line Automatic Test Equipment.

Although this list of interface documents is not complete, it is an indication of the various documents that have been developed in an attempt to standardize interfaces. The hardware interface can be categorized as physical, performance, and contractual. The physical interfaces are determined by dimension, connector callout, pin designation, fluid coupling, etc. The performance interfaces comprise electrical, mechanical and information format and content. Contractual interfaces are physical and performance interfaces that can be controlled and checked by qualification and acceptance testing. The hardware interfaces (physical and performance) are contractual. During acceptance testing, the information available for determining compliance is normally at the surface of the package and through connectors and/or couplings. Because of this contractor-customer contractual interface, the standardization of interfaces for specific types of hardware will result in reduced life cycle costs.

The selection of an interface for use between equipment and a data bus (on-line and off-line) is based on the following:

- **Performance** -
  - -- Data rates determine the type of bus. Parallel buses are faster while serial buses are slower but better over long distances.
  - -- Information content across the interface will determine the word length requirements.
  - -- Electrical interfaces are controlled by the bus I/O modules.
- **Physical** -
  - -- Physical interfaces are controlled by the bus I/O modules.
- **Contractual**
  - -- Contractual interfaces are those (performance or physical) that can be controlled and checked by qualification and acceptance testing.

Because of the varied performance requirements, no one interface will meet the requirements of all users. A standard shopping list of interfaces should be available for selection to meet the user's performance requirements. DOD-STD-1399, being a general standard, and MIL-STD-XXXX (NOSC Proposed) are the logical places to place these shopping lists. This shopping list would reference the other data bus interface standards by type and use.

MIL-STD-XXXX (NOSC)

MIL-STD-XXXX (NOSC Proposed) presents a methodology of developing a set of sections or MIL-STDS that are devoted to the standardization of performance monitoring for classes of hardware. Three levels of interface are proposed to allow flexibility in meeting the user's tolerance requirements.

MIL-STD-1657

MIL-STD-1657 is primarily a physical interface document that is referenced by MIL-S-17000. This is applicable to combat systems.

Ships Data Multiplexer System (SDMS) Equipment Specification

The SDMS I/O modules standardize the interface between the SDMS and shipboard equipment. This will be applicable to ships that will have the SDMS system.

MIL-STD-1553

MIL-STD-1553 specifies a type of series data bus. This was developed primarily to reduce the amount of hardwiring in aircraft.

MIL-STD-1397

MIL-STD-1397 is an interface document primarily concerned with computers and the following digital bus interfaces:

- Type A (NTDS slow);
- Type B (NTDS fast);
- Type C (ANEW);
- Serial.

DOD-STD-1399

DOD-STD-1399 with supporting sections specifies interfaces for shipboard equipment. These interfaces include the following types:

- Support Services (Environmental):
- Electronic Information (Functional);
- Controlled Factors (Environmental);
- Weapons Control (Functional);
- Uncontrolled Environment (Environmental);
- Operational Factors (Environmental);
- Electrical Information (Functional);
- Mechanical Information (Functional).

The physical types of interfaces are specified under "controlled factors (environmental)". An example of this is Digital Computer Grounding (Section 406, MIL-STD-1399) where MIL-C-915 cable is specified. This is similar to the approach used by MIL-STD-1657 which specifies physical parameters, but is a subtier document of MIL-S-17000. MIL-S-17000 is an equipment specification whereas Section 406 is a subset of a MIL-Standard (MIL-STD-1399).

IEEE STD-488

IEEE STD-488 is a parallel digital interface bus that was developed for a family of programmable test equipment.

On-Line/Off-Line Interface (Proposed)

The establishment of a standard on-line/off-line interface would apply to new designs. This would require a means to balance performance monitoring with classical BIT. The differences

between performance monitoring and the classical BIT are well explained in Section 3.2.7 (Tolerances) of the Built-In-Test Design Guide, June 1980. Classical BIT is more concerned with catastrophic failure and isolation to support a maintenance concept than how well the equipment is working. Performance monitoring (how well the equipment is working) requires tighter tolerances than the classical BIT.

A problem exists in preserving data integrity where tight tolerances are required. The sensed information first exists in electrical (volts, amps, frequency, etc.) or physical (pressure, temperature, etc.) form. This information becomes data only when it is interpreted by a person or machine. This occurs in the following ways:

- A person reads an instrument display and interprets the data (the tolerances of the data are based on the sensor and display meter);
- The information is sensed and sent over a transmission line prior to being interpreted as above. This sending of information over transmission lines causes degredation;
- The information is sensed and converted to a digital form (data) prior to sending over the transmission line. This tends to preserve the data and ease the problem when the data must be sent to a place removed from the hardware.

In the future, the interpretation of sensed performance data can be used to detect and/or predict failures. The prediction of failures permits implementation of preventive maintenance prior to catastrophic failures. The classical BIT would be used to isolate failures at the operational level. This approach will probably require a standard family of sensors that converts information directly to the digital data state. The proposed on-line/off-line interface MIL-STD would contain this family of standard sensors along with methods for their application and evaluation. The primary emphasis would be on the characteristics at the interface. This proposed interface MIL-STD or section would be a subset of MIL-STD-XXXX (NOSC Proposed). MIL-STD-XXXX subsets would also cover the types of data that are required, by equipment class, to have performance monitoring. The projected result of the increase in LSI technology, including self-test, will allow for greater self-contained BIT in future military hardware. This increased capacity will allow the BIT to perform much of what an off-line tester currently does.

MIL-STD-1326

MIL-STD-1326 should be replaced by MIL-STD-XXXX (NOSC Proposed). The sections on selection of test points and characteristics fit better in MIL-STD-415. The deliverable items are Test Requirements Data (TRD), covered in MIL-STD-2076. Since MIL-STD-1326 was drafted in the late 1960s, the interface portion needs updating and will fit better in MIL-STD-XXXX (NOSC Proposed).

5.0 CONCLUSIONS

5.1 GENERAL

Established design disciplines such as performance, maintainability, etc., are adequately backed by military specifications and standards. The subject of "testability" as a design discipline does not currently exist in military specifications and standards for use in procurement. Many military documents exist, old and recent (MIL-STD-415, MIL-STD-1326, MIL-STD-2076, etc.), that contain testability hardware requirements, but not testability as a design discipline. Also, conflict and overlap exist between different documents when different agencies have developed their own document to perform an identical function. The specific conclusions (paragraph 5.2) are presented by the following testability functions:

- Management
- Technical Requirements
- Design Guide
- Documentation
- Validation
- Interfaces

5.2 SPECIFIC CONCLUSIONS

Management - Testability does not currently exist as a design discipline as do the disciplines of performance, maintainability, safety, etc. Heretofore, testability has been implemented through the maintainability design discipline using MIL-STD-470 as the management document. However, the satisfaction of contractual maintainability goals (e.g., MTTR) does not in and of itself ensure a highly testable design. A similar document for management of testability by an R&D contractor is required to enhance testability interests. These management elements are available in the W. Keiner document, "A Study of Testability Standardization for Electronic Systems and Equipment", and are proposed as MIL-STD-ABC, "Testability Program Requirements".

Technical Requirements - Since testability does not exist as a design discipline in equipment specifications and general standards, MIL-STD-490, "Specification Practices", does not currently make provisions for testability as a specification item as it does with maintainability and reliability. Also, general standard, MIL-STD-454, does not have a requirement that is dedicated to the subject of testability. Requirement 32, Test Provisions, is associated with the hardware requirement; however, it doesn't address the design discipline of testability. As a point of illustration, MIL-STD-454 specifies the maintainability requirement by function as follows:

- MIL-STD-470 Maintainability Program
- MIL-HDBK-472 Maintainability Prediction

- MIL-STD-471 Maintainability Verification

As previously noted, this approach to Testability does not currently exist in released form. MIL-STD-XXX Proposed, W. Keiner, "Testability Acquisition Program Requirements for Electronic Equipments and Systems", covers these topics in a single document.

MIL-STD-415, Test Provisions for Electronic Systems and Associated Equipment, Design Criteria, contains a mix of design, management, and documentation requirements.

Design Guide - A design guide is not a contractual document during the procurement of hardware. The design guide is supplied to the hardware contractor as an instrument to disseminate information.

The BIT design guide fulfills this information criteria for the classical case. The classical BIT was developed to meet the requirements of the maintenance concept. Due to this fact, BIT is limited to GO/NO-GO testing that determines equipment readiness for operation and for failure localization. It does not tell how well the equipment is working.

A design guide for operational monitoring does not currently exist. An operational monitoring design guide that depicts methods of implementing performance monitoring would support the ORMS concept.

The W. Keiner document, Design for Testability Course, depicts the methodology for implementing testability into the hardware. This course would fulfill the criteria for disseminating overall testability information provided that contractor personnel would have access to it. An overall testability design guide will aid in the education process.

MIL-STD-1390, Level of Repair, may be used in making testability design trade-off studies.

MIL-STD-1365, Standard General Purpose Electronic Test Equipment, provides a shopping list for use by hardware contractors.

Documentation - The following types of documentation are associated with testability:

- Performance Specification (MIL-STD-490)
- Testability Analysis and Report (Proposed)
- Test Requirements Data (TRD)
- Testability Demonstration (Proposed)
- Technical Support Plan (TSP)
- Test Program Sets (TPS)
- Technical Repair Standards (TRS)
- Restoration, Overhaul, and Repair (ROR)

Although MIL-STD-490 was discussed under technical requirements, it is also applicable here because the performance specifications may become an equipment specification depending on the production volume.

A test analysis and report MIL-STD does not currently exist in released form. This type of analysis, if performed during the hardware development, would influence the design.

Overlap and conflict exists between the following Test Requirements Data (TRD) MIL-STDs:

- MIL-STD-1519
- MIL-STD-1345
- MIL-STD-2076

MIL-STD-2076 is the more current of the three documents. This MIL-STD pertains to the use of ATE, ATLAS and Test Program Sets (TPS).

The callout for CDRL items and DIDs pertaining to testability demonstration plans, procedures and reports does not currently exist. A testability demonstration MIL-STD similar to the maintainability demonstration, MIL-STD-471, does not exist in released form.

The technical support plan (TSP) document, MIL-T-24309, does not contain reference to the Test Requirements Data (TRD) as specified in MIL-STD-1519, MIL-STD-1345 or MIL-STD-2076.

The test program sets (TPS) document, MIL-STD-2077, being slanted towards avionics, is not sufficiently universal for use outside NAVAIR.

The following technical repair standard (TRS) documents were reviewed as part of this study:

- MIL-STD-2111, Technical Repair Standards (4G repairables), Preparation of
- MIL-T-24255, Technical Repair Standards (For Submarines Only)
- MIL-T-24424, Technical/Maintenance Overhaul and Repair Standards

These documents are specialized and perform different functions. MIL-STD-2111 is for depot repair. MIL-T-24255 is for the overhaul of submarines and MIL-T-24424 is for the overhaul of ships. MIL-STD-2111 does not make specific provisions for ATE and TPS. MIL-STD-3110, Restoration, Overhaul, and Repair of Electronic Equipment, is listed under documentation because testing is a part of it. In the tier of documents, MIL-STD-3110 uses TRS which are covered in MIL-STD-2111, MIL-T-24255, and MIL-T-24424.

The general purpose electronic test equipment (GPETE) is shown in Figure 4, Testability Related Data Flow, for those cases where ATE is not used. The GPETE data are specified in the TRD and used in the TRS and ROR documents. The TRS/ROR documents utilize the TRD, GPETE and TPS data.

Validation - MIL-STD-471 places its priority on how long test equipment must operate. This opposes the more important testability aspects of how effectively the test equipment works. The controlling factor is the Mean Time To Repair (MTTR) parameter. A document does not exist in released form to control the demonstration of the testability of the hardware.

Interfaces - Many documents have been developed in an attempt to standardize physical, performance and contractual interfaces. Because of the varied requirements by different users, a single interface will not satisfy everyone. A limited shopping list of interfaces is the logical solution. DOD-STD-1399, being a general standard, is the logical place to put the shopping list.

A MIL-Document that deals with the concept of performance monitoring does not currently exist in released form. The existing testability related MIL-documents, with the exception of MIL-STD-1326, deal with satisfying the maintenance concept. The maintenance concept deals with how the equipment is operating as well as with isolating failures. It does not address how well it is working. MIL-STD-1326 does not meet the current state of the art in testability technology.

MIL-STD-XXXX (NOSC Proposed), "System Level Performance Monitoring, General Requirements", addresses the subject of performance monitoring. A methodology for developing a set of sections or MIL-STDs by classes of shipboard hardware for performance monitoring is presented in MIL-STD-XXXX. Performance monitoring requires tighter tolerances than the testing associated with meeting the maintenance concept. This will require a family of interface devices that transfers the physical (pressure, temperature, etc.) and electrical performance (volts, frequency, etc.) parameters directly to the information state (digital). An On-Line/Off-Line interface document does not currently exist to document and specify this family of interface devices. The projected increase in LSI technology, including self-test, will permit greater self-contained BIT in future hardware. This increased capability will allow the BIT to perform much of what an off-line tester currently does. This future BIT capability will be part of the family of interface devices.

6.0 RECOMMENDATIONS

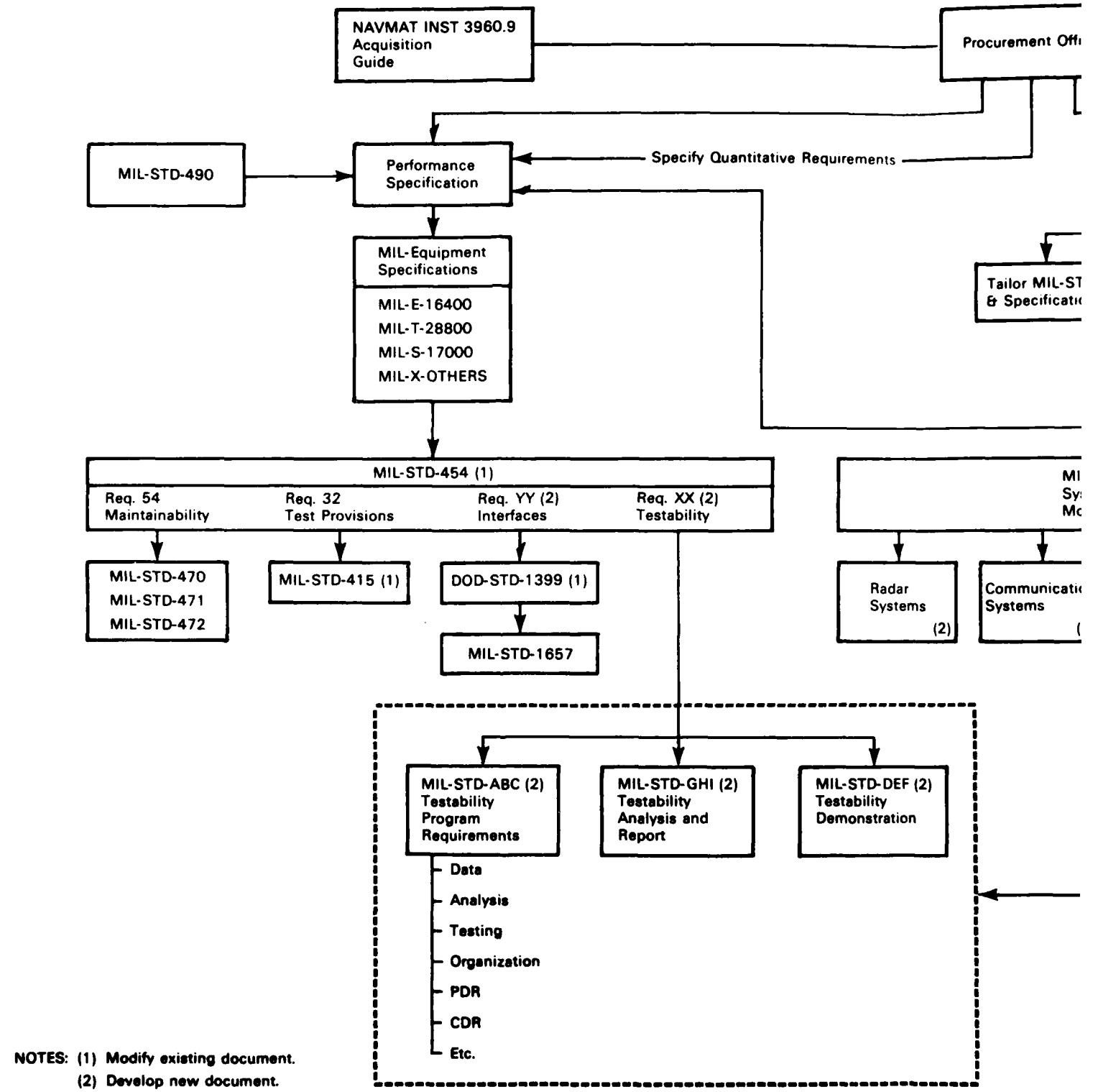
6.1 GENERAL

The establishment of testability as a design discipline will require generation of a family of testability documents that can be applied when procuring hardware. This will require:

- Generation of new military documents;
- Cancellation of some military documents;
- Modification of some military documents.

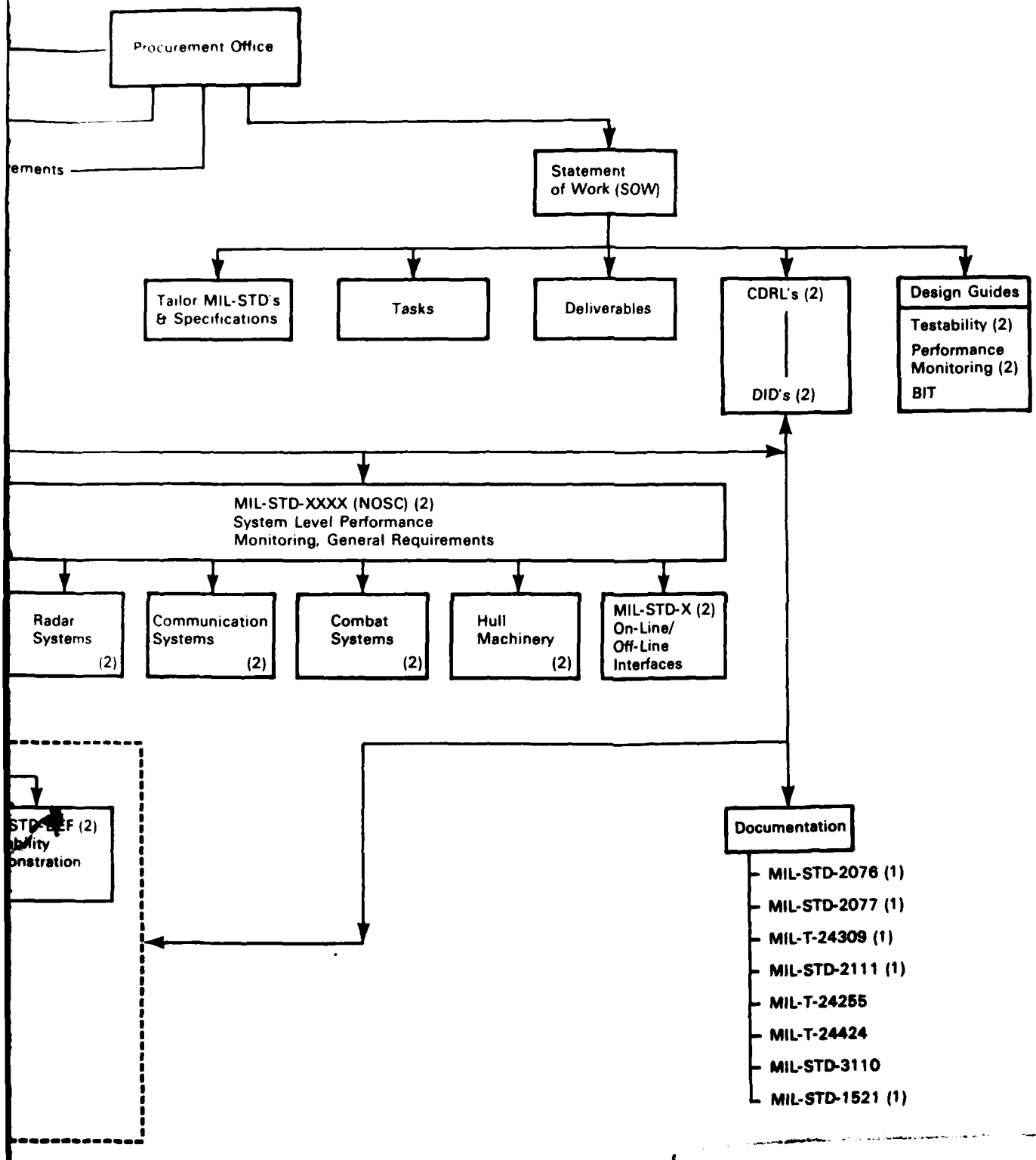
The recommended hierarchy of testability documents relative to the procurement of hardware is depicted in Figure 5. The following footnotes in Figure 5 apply as follows:

NOTES: 1. Modify existing document - Change the existing document to avoid conflict with other documents and/or to specify testability requirements.



NOTES: (1) Modify existing document.
(2) Develop new document.

Figure 5. Recommended Hierarchy of Testability D



ded Hierarchy of Testability Documents

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2. Develop New Document - A new MIL-document is required to specify testability requirements and/or complete the family of testability documents

The generation, cancellation and/or modification of each applicable military document is discussed in paragraph 6.2 under the following testability functions:

- Management
- Technical Requirements
- Design Guide
- Documentation
- Validation
- Interfaces

6.2 SPECIFIC RECOMMENDATIONS

Management - A Testability Program document (MIL-STD-ABC, Proposed), similar to MIL-STD-470 for maintainability, should be developed. This testability program document would be derived from the program elements contained in the W. Keiner work, "A Study of Testability Standardization for Electronic Systems and Equipment".

Technical Requirements - The following will be required to establish testability as a design discipline and develop a family of MIL-documents that passes testability requirements to allied documents:

- Modify MIL-STD-490 to include testability requirements;
- Modify MIL-E-16400, MIL-T-28800, etc., to include testability requirements, and to specifically include a reference to MIL-STD-454;
- Modify MIL-STD-454 to include requirement sections for testability and interfaces. The testability requirement would call out the following MIL-STDs proposed:
  - Testability Program Requirements (MIL-STD-ABC)
  - Testability Analysis and Report (MIL-STD-GHI)
  - Testability Demonstration (MIL-STD-DEF)

NOTE: The three-document approach is in parallel with that approach used by maintainability. The proposed interface section for MIL-STD-454 would reference MIL-STD-1657 and possibly MIL-STD-1399.

- Modify MIL-STD-415 to contain only design and hardware requirements. The management information should be in the proposed MIL-STD-ABC "Testability Program Requirements". The documentation requirements should be in the TRD document;

- Technical requirements as well as the test point placement and compatibility aspects of testability must be stated for the build-in test. Whether or not their statement is best promulgated under a single document (modified MIL-STD-415) or under two documents is unresolved at this time.

Design Guide - The following testability design guides should be developed to aid in the testability educational process:

- Performance Monitoring Testability Design Guide which presents methods and examples of performance monitoring in hardware;

- An overall Design for Testability Guide should be developed. The conversion of the W. Keiner document, "Design for Testability Course", to a written test will fulfill this need.

Documentation - The following modifications are needed in the testability documentation area:

- Modify MIL-STD-490 to include testability requirements;

- Develop a test analysis and report (MIL-STD-GHI) utilizing data from the W. Keiner report, "A Study of Testability Standardization of Electronic Systems and Equipment";

- Develop a test requirements data (TRD) MIL-STD (TBD) utilizing MIL-STD-2076 as a base. This would replace MIL-STD-1519 and MIL-STD-1345;

- Modify MIL-T-24309 to reference test requirements data (TRD) as specified in MIL-STD-1519, MIL-STD-1345 or MIL-STD-2076;

- Modify MIL-STD-2077 to cover more than avionics;

- Modify MIL-STD-2111 to cover ATE and TPS;

- Develop CDRL Item and supporting DIDs;

- Modify MIL-STD-1521 to include testability in checklists for the design reviews (SRR, SDR, PDR, CDR) and audits (FCA, PCA).

Validation - Develop a testability demonstration MIL-STD-DEF similar to the maintainability demonstration document, MIL-STD-471. Utilize data from the W. Keiner report, "A Study of Testability Standardization for Electronic Systems and Equipment". This will include the testability demonstration plan, procedure and report.

Interfaces - The following recommendations are submitted to standardize interface requirements.

- Utilize DOD-STD-1399 as the general standard for interfaces.

- Cancel MIL-STD-1326. The section on test points and characteristics should be in MIL-STD-415. The deliverable items are Test Requirement Data (TRD) and should be in MIL-STD-2076. The remainder is obsolete.

- Develop MIL-STD-XXXX (NOSC Proposed) to replace MIL-STD-1326.

- Develop an On-Line/Off-Line Interface document that specifies a family of interface devices that convert physical and electrical performance parameters to an information state (digital).

Implementation - What has been presented herein in a roadmap for the development of the MIL-documents required to facilitate making testability happen in military equipment. The next logical question is, "which roads do we take and when?" The functional partitioning utilized in this study is also useful for dividing the work that should follow. Each functional area can be approached separately (with due attention to interactions) for the definition of work to be done and for the generation of documents.

The following program is recommended. Each functional area should be investigated more deeply to turn this generalized plan into a more detailed implementation plan. These plans should be sufficiently detailed to serve as a basis to effectively estimate the time and effort required to achieve the final goal. Specifically, they should answer the following questions:

- What effort is required to develop all the documents required?

- What is the total time required and interim milestones?

- What supporting documentation (from other areas) is required for the interim milestones?

- What supporting technology development/investigation is required?

- Can an overall time-phased implementation provide meaningful interim products?

- What existing work is available?

- What can a "trial run" accomplish?

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